CHAPTER 4

APPLICATION OF CRITERIA

4-1. Introduction. This chapter provides guidance for the application of the criteria specified in chapter 3. Chapter 4 is concerned with the building as a whole. Procedures for designing and detailing of the structural elements of a building are discussed in chapters 5 through 10. Detailed examples for specific types of structures are included in appendix D of this manual.

a. Expected performance. The general objectives are approached with reference to a major level (or maximum expected level) of earthquake ground motion having a 10 percent probability of exceedance in 50 years. This ground motion is characterized by a peak ground acceleration, Z, and a site spectrum, ZC, that are functions of the fundamental period of vibration, T. ZC sets the force for a structure that remains elastic at 5 percent of critical damping during this ground motion. It is impracticable to design for this level of force; moreover, it is not necessary because a building that is designed to reach its elastic limit at lower force levels can survive the earthquake by yielding and absorbing energy. SEAOC recommendations provide criteria for structural systems that are expected to safeguard against major failures and loss of life at the ground motion represented by ZC, when designed to a force level that is reduced through a response modification coefficient, R_w. The designer must be aware that designing the lateral force resisting elements for the reduced force level does not, in itself, necessarily ensure satisfactory performance. Special details for structural elements and connections are required to enable the structure to deform beyond the elastic limits of the materials. For buildings that may have unusual behavior, additional design criteria may be required to develop satisfactory performance.

b. Overview of the design procedure. The design procedure follows the general pattern listed below—

(1) The building as a whole.
- (a) Geologic conditions; Z, S. (para 4-2)
- (b) Facility conditions: I, H. (para 4-3)
- (c) Selection of method of analysis. (para 4-4)
- (d) Selection of structural system. (para 4-5)
- (e) C-factor and period: C, T. (para 4-6)
- (f) Base shear and weight: V, W. (para 4-7)
- (g) Principal axes of building. (para 4-8)
- (h) Distribution of lateral forces. (para 4-9)
- (i) Consideration of vertical forces. (para 4-10)
- (j) Detailed design requirements. (para 4-11)
- (k) Deformation requirements. (para 4-12)
  - *1*. Connections. (para 4-13)
  - *2*. The diaphragms. (para 4-14)
  - *3*. The elements and components. (para 4-15)
  - *4*. Nonbuilding structures. (para 4-16)
  - *5*. Design procedure.
    - *(a)* Planning. (para 4-17)
    - *(b)* Design. (para 4-18)

c. Basis of design. When developing seismic design criteria, there must be consistency on both sides of the demand versus capacity equation. Demand represents the applied forces resulting from the earthquake (i.e., the demands of the earthquake). Capacity represents the ability of the structural elements to resist the earthquake forces (i.e., the capacity of the structure). The basis for earthquake design is to supply sufficient capacity to satisfy the demands, that is, capacity equal to or greater than the demand. There are three general bases of design that are used in seismic design:

(1) *Allowable stress.* For this basis of design, the demands of the earthquake are reduced to a level that is consistent with working stress or service level procedures for calculating capacity. The factor R_w is used to reduce the site spectrum to a building design spectrum, with the subscript w representing working stress. For steel (under ASD) and wood, capacities are calculated on the basis of allowable stresses, which are set at some fraction of the strength of the material. For reinforced concrete, the demand is increased by load factors because capacities are calculated on a strength basis, and the load factors are set so that the basis of design is consistent with the working-stress basis for the other materials. This working-stress procedure is the basis for seismic design used in this manual.

(2) *Strength.* For this basis of design, the demands of the earthquake are reduced to a lesser degree for consistency with the strength basis for calculating the capacity of the structural elements. The factor R is used to reduce the site spectrum, and no load factors are applied to the seismic demand. (R_w is approximately equal to 1.5R.) This is the basis of design that was used for Applied Technology Council document ATC 3-06 which was the forerunner of the National Earthquake Hazard Reduction Program (NEHRP) seismic design provisions Federal Emergency Management

Agency (FEMA 95). For reinforced concrete, member capacities are calculated on the strength basis, in the same way they are under the working-stress basis of design, but R is used rather than R_w, and there is no load factor. For the other materials, which do not as yet have strength procedures, member capacities are calculated on a working-stress basis but with higher allowable stresses which are intended to be consistent with the use of R rather than R_w. It can be expected that when strength procedures are developed for wood, steel, and masonry, the working-stress basis will be abandoned. It should be noted that TM 5-809-10-1/ NAVFAC P-355.1/AFM 88-3, Chap 13, Sec A uses a strength basis for meeting the demand of EQ-I. There is no reduction factor R, but EQ-I is a smaller earthquake than that assumed in the other bases of design, and some yielding of structural elements is accepted.

(3) *Performance*. For this basis of design, there is no reduction of the forces associated with the site spectrum, but the structure is evaluated for its ability to absorb energy, deform inelastically, and exhibit ductile behavior. TM 5-809-10-1/ NAVFAC P-355.1/AFM 88-3, Chap 13, Sec A uses this basis of design for meeting the demand of EQ-II.

4-2. Site conditions. Guidance on the determination of Z and S is given in the following paragraphs.

a. Zone factor. The Z-factor represents the seismicity of the site. It is a measure of the effective peak ground acceleration having a 10 percent probability of exceedance in 50 years. The value of Z ranges from 0.40 in Seismic Zone 4 to 0.075 in Zone 1. The Z values and the seismic zone map are obtained from chapter 3. The SEAOC Seismic Zone 2 has been subdivided for assignment of the Z-factor: Zone 2A on the map, in the eastern and midwestern states, uses Z = 0.15; Zone 2B on the map, in the western states, uses Z = 0.20. The other SEAOC requirements for Zone 2 apply to both Zone 2A and Zone 2B on the map.

b. Soil factor. The value of S is determined from the characteristics of the soil profile at the building site. The soil profile will be established from properly substantiated geotechnical data, and the S-factor will be determined from SEAOC Table 1-B. Generally, the value of S will vary from 1.0 to 1.5. In special cases it may be equal to 2.0.

(1) When geotechnical data are not available, the S-factor will be taken as 1.5.

(2) The S_4 profile was established in recognition of the potential for soft site effects such as those that exist in portions of Mexico City and those that were experienced to a lesser extent in some areas of the San Francisco Bay Area during the October 17, 1989, Loma Prieta earthquake. Soft sites such as filled-in lake beds or filled-in waterfront property may exhibit characteristics that amplify earthquake ground motion in the moderate-to-long structural period range (e.g., 1.0 to 3.0 seconds). When there is evidence that such a condition may exist, a geotechnical investigation will be required. Refer to SEAOC lD8b(4) and lF2d.

4-3. Facility conditions. The building occupancy and height categories are required at the initial stages of seismic design.

a. The occupancy categories are defined in SEAOC Table 1-C as modified in chapter 3. The importance factor, I, is determined from SEAOC Table 1-D.

b. The height of the building, H, is involved in a number of system limitations. Height limits that trigger various requirements are 65, 120, 160, and 240 feet, as shown in SEAOC Table 1-G and other parts of SEAOC.

4-4. Selection of method of analysis. The SEAOC recommendations prescribe two lateral force procedures (SEAOC 1D8): one is the static lateral force procedure; the other is the dynamic lateral force procedure. As will be seen in the summary below, most structures will be designed by the static lateral force procedure of SEAOC 1E. Structures that do not qualify for the static lateral force procedure will require a dynamic analysis. Instead of using the provisions of SEAOC 1F, the dynamic analysis will be done according to TM 5-809-10-1/NAVFAC P-355. 1/AFM 88-3, Chap 13, Sec A. All structures located on Soil Profile Type S_4 and having a period greater than 0.7 seconds, will have a dynamic analysis. The other provisions of SEAOC 1D8 are summarized below.

a. Zone 1. The static procedures of SEAOC lE may be used for all structures unless in soil S_4 and period greater than 0.7 seconds.

b. Zone 2, Occupancy Category IV. The static procedures of SEAOC lE may be used for all structures unless in S_4 and period greater than 0.7 seconds.

c. Zone 2, Occupancy Categories I, II, and III. The same provisions as used in Zones 3 and 4.

d. Zones 3 and 4. The static procedures of SEAOC lE may be used for the following structures.

(1) Regular structures under 240 feet in height with lateral resistance provided by systems listed in SEAOC Table 1-G, unless in S_4 and period greater than 0.7 seconds.

(2) Irregular structures not more than 5 stories or 65 feet in height.

(3) Structures having a tower on a platform, as defined in SEAOC 1D8a(4).

4-5. Building systems.

a. Space frame. Basic to understanding the structural systems is the concept of the space frame. The term *space frame* refers to the three-dimensional assemblage of structural elements. A complete space frame is one that consists of beams and columns that carry all of the gravity loads. When some of these frame elements are designed to resist seismic forces as well, the designated elements make up the frames that become the moment frames of the lateral force resisting system. Refer to figure 4-1. In an “incomplete” space frame, some frame elements are missing and floor framing is carried by shear walls or braced frames that are part of the lateral force resisting system. In other words, if the walls and braces are removed there will not be a complete gravity support system.

b. Structural systems.

(1) Bearing wall system (category A, SEAOC Table 1-G). This system is characterized by shear wall or braced frame lateral force resisting elements that also support vertical loads (i.e., gravity loads).

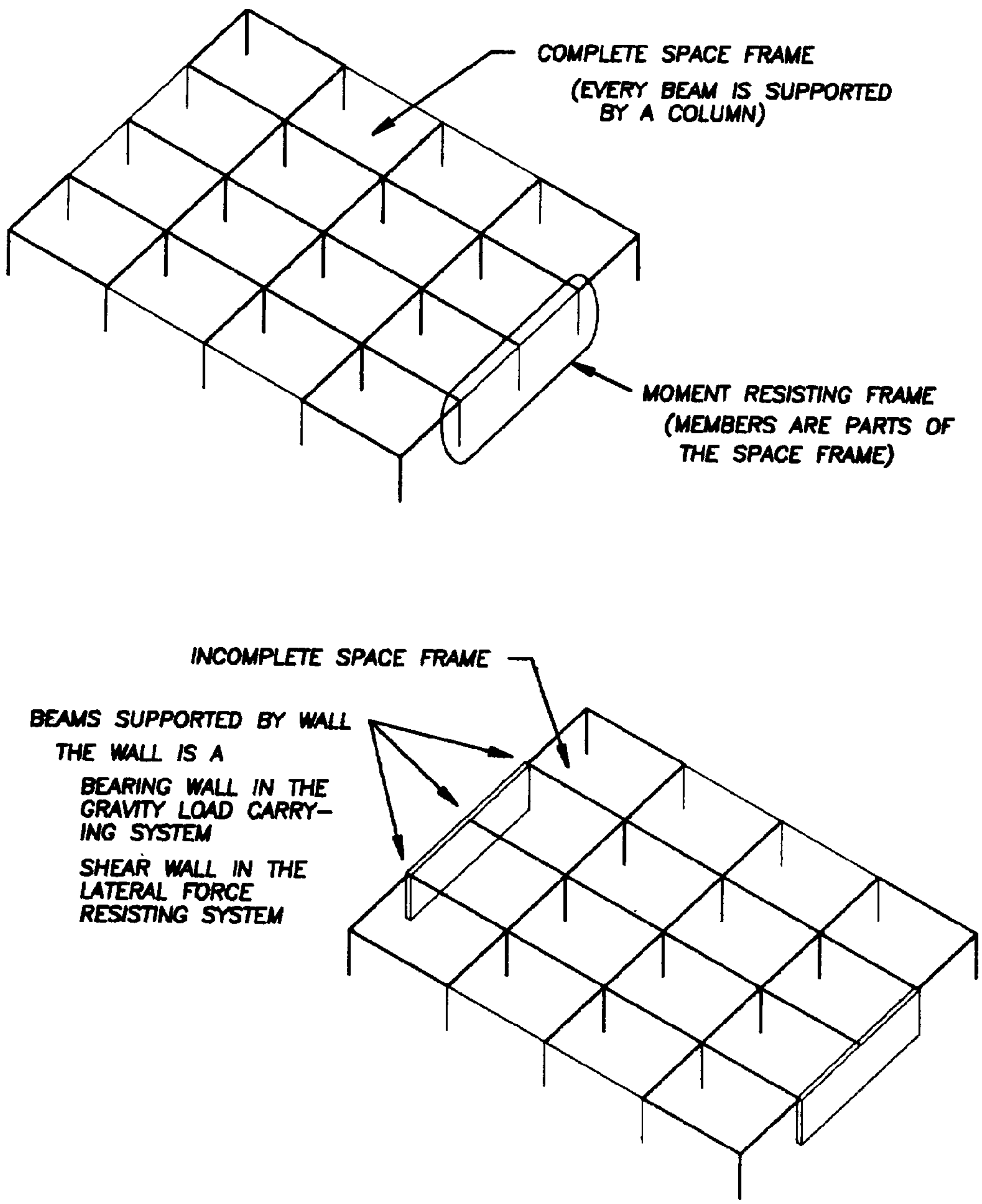


Figure 4-1. The space frame and the designated seismic moment resisting frame.

If these elements fail due to lateral loads, there will be a loss of the vertical load capacity of a portion of the structure that can lead to a partial collapse or to vertical instability of the building.

(2) Building frame system (category B, SEAOC Table 1-G). This system consists of a complete vertical load carrying space frame, with lateral load resistance provided by braced frames or nonbearing shear walls. This definition requires that the vertical load carrying frame be essentially complete. However, some exceptions are acceptable, such as minor load bearing walls around a stairwell if they do not significantly influence the lateral force characteristics or the vertical load capacity of the building. Also, basement walls below the level considered the base of the building may be bearing for loads originating at that level. The test for qualifying as a vertical load carrying space frame is to determine whether or not the building can support the vertical loads if the shear walls or braces are seriously damaged during an earthquake. While there is no requirement to provide lateral resistance in the vertical load framing, it is strongly recommended that nominal moment resistance be incorporated in the vertical load frame design. In structural steel, this might be in the form of nominal moment resisting beam flange and/or web connections to the columns. In reinforced concrete, the nominal moment resistance inherent in cast-in-place concrete may be considered sufficient to qualify for this system, while most types of precast concrete systems would not.

(3) Moment resisting frame system (category C, SEAOC Table 1-G). The lateral force resisting systems are moment resisting frames. As in the case of the building frame system, the vertical load carrying frame must be essentially complete. The moment resisting frames must be capable of resisting the entire lateral force.

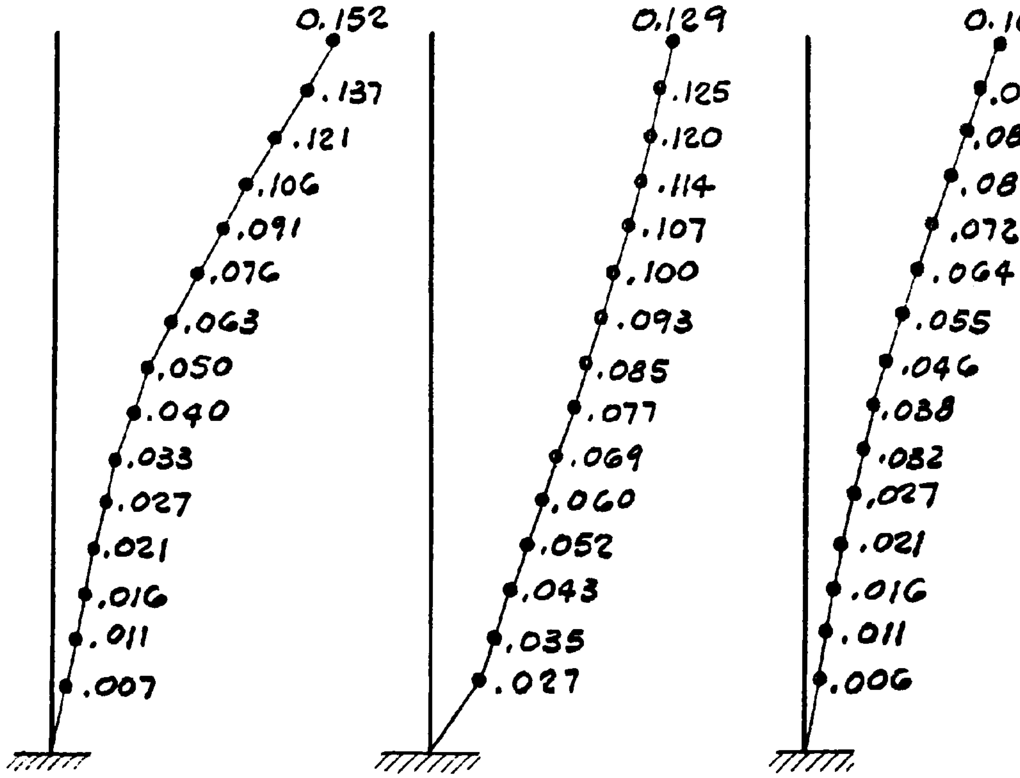
(4) Dual systems (category D, SEAOC Table 1-G). Dual systems are interactive combinations of shear walls or braced frames with moment frames. Generally, for tall buildings with a dual system, the shear walls, if they were to act independently, would deflect as vertical cantilevers, with greater interstory displacements occurring at the top, while the frames would deflect at a more uniform rate or with greater interstory displacements at the bottom (see fig 4-2). Usually in buildings that have a dual system, the diaphragms are rigid. With rigid diaphragms there is a forced compatibility of frame and wall deflection at each story, and this induces interaction forces between shear walls and frames. The pattern of these forces is such that the shear walls tend to support the frame at the lower stories and the frame tends to support the shear walls at the upper stories. In order to qualify as a dual system, the vertical load carrying space frame must be substantially complete. Special details are required according to the R_w value and seismic zone. The shear wall or braced frame and moment resisting systems will conform to both of the following criteria—

(a) The frame and shear walls or braced frames shall resist the total required lateral force in accordance with relative rigidities considering the interaction of the walls and frames as a single system. This analysis shall be made in accordance with the principles of structural mechanics considering the relative rigidities of the elements and torsion effects in the system. Deformations imposed upon members of the frame by the interaction with the shear wall or braced frame shall be considered in this analysis.

(b) The special moment resisting frame acting independently shall be capable of resisting not less than 25 percent of the total required lateral force, including torsion effects. Columns of the frame system may also function as the boundary elements of shear walls. As such, these columns must be designed to resist the vertical forces resulting from overturning moment in the shear wall along with the load effects associated with the frame system.

(5) *Undefined systems.* Undefined systems are those not listed in SEAOC Table 1-G; they are assigned to category E in the table. This category includes such structures as A-frames, three-hinged arches, and rigid frames of wood. Such structures must have their basis of design justified in accordance with SEAOC 1D9b.

c. R_w-factor. Each of the four categories A, B, C, and D has a set of systems that are defined by their materials and characterized by a particular response modification coefficient, R_w. The $1R_w$ factor represents the type of structural system and the nature of the structure itself. The value of R_w, which is obtained from SEAOC Tables 1-G and 1-I, varies from 4 to 12 for buildings and from 3 to 5 for nonbuilding structures. Buildings that are considered to possess considerable inelastic deformation ability and/or have inherent redundancy are assigned the higher R_w values. Buildings that tend to be more brittle and lack redundancy are assigned the lower R_w values. Damping, to a certain extent, is also considered in the R_w value. Whereas buildings generally have a multiplicity of nonstructural and noncomputed resisting elements that effectively increase the resistance of the structure, structures other than buildings (i.e., nonbuilding structures) generally do not have such elements or have low damping characteristics and are assigned lower R_w values. Although the selec-



a.) SHEAR WALL ACTING INDEPENDENTLY (deflection shown for total building forces)

b.) MOMENT FRAME ACTING INDEPENDENTLY (deflections allow for 25% of total building forces)

c.) DUAL SYSTEM SHEAR WALL AND MOMENT FRAME LINKED TOGETHER BY RIGID DIAPHRAGMS. (deflection shown for total building forces)

DISPLACEMENTS IN FEET

Figure 4-2 Dual-system deformations.

tion of the R_w value is generally a simple process, for some buildings it may be complicated by unusual combinations of materials, height limitations, and special detailed system design requirements.

d. System limitations. System limitations involve building configuration, vertical and plan irregularities, combinations of systems, and height limits.

(1) *Configuration requirements.* The designer is required to designate the structure as either regular or irregular (SEAOC 1D5). Irregular features include, but are not limited to, those described in SEAOC Tables 1-E and 1-F. The irregularity of a building should be obvious: the definitions given in the tables were developed only to meet a need for definite limits. The designer is not expected to make these calculations routinely, but only when needed to resolve doubts in marginal cases. Irregularities have certain consequences that are summarized below. It should be noted that where dynamic analysis is mentioned it is a general requirement, but most buildings are exempted under SEAOC 1D8.

(2) *Vertical irregularities* (SEAOC Table 1-E).

(a) Stiffness. Note the exception of SEAOC 1D5b(1). The presence of a stiffness irregularity requires dynamic analysis, except for buildings exempted under SEAOC 1D8.

(b) Weight. Note the exception of SEAOC 1D5b(1). The presence of a weight irregularity requires dynamic analysis, except for buildings exempted under SEAOC 1D8.

(c) Geometry. Geometric irregularities require dynamic analysis, except for buildings exempted under SEAOC 1D8.

(d) Discontinuities. In-plane discontinuities in buildings in Zones 2, 3, and 4 invoke the overturning requirements of SEAOC 1E7b.

(e) Weak stories. Weak stories invoke the system limitations of SEAOC 1D9a.

(3) *Plan irregularities* (SEAOC Table 1-F).

(a) Torsion invokes the requirement for amplification of accidental torsion of SEAOC 1E6d, the orthogonal effects of SEAOC 1H1c, and, in Zones 3 and 4, the diaphragm requirements of SEAOC 1H2j(4).

(b) Re-entrant corners invoke the diaphragm requirements of SEAOC 1H2j(4) and (5).

(c) Diaphragm discontinuity in Zones 3 and 4 invokes the diaphragm requirement of SEAOC 1H2j(4).

(d) Out-of-plane offsets invoke, in Zones 2, 3, and 4, the overturning requirements of SEAOC 1E7b and, in Zones 3 and 4, the diaphragm requirements of SEAOC lH2j(4).

(e) Nonparallel systems are subject to the requirements of SEAOC 1H1c concerning orthogonal effects.

(4) *Combinations of structural systems.* A building can utilize two or more systems in combination. Combinations may be horizontal or vertical or both. An example of a vertical combination is a building having shear walls in a base structure with a moment frame tower above. A horizontal combination means different systems in the two directions (e.g., moment frames in one direction and shear walls in the other). Each direction (system) is treated individually, with due regard for effects that result from interaction, such as torsional effects.

(a) Vertical combinations. Generally the R_w value is constant throughout the height of the building. When a change of structural system does occur (e.g., a steel frame on concrete shear walls, a wood box system on a concrete box system), the R_w value at the lower level cannot be greater than the R_w value of the system above, and special consideration must be given to the transition from one system to the other to ensure sufficient load transfer capacity and inelastic deformation capability. Refer to SEAOC 1E3a.

(b) Combinations in plan. The lateral load resisting system parallel to one axis may be different from that along the other axis (e.g., shear walls or braced frames in the north-south direction and moment frames in the east-west direction). There is an important restriction relating to bearing wall systems: if the structural system in one direction is a bearing wall system (category A in SEAOC Table 1-G), then no matter what the system is in the other direction, the R_w used in that other direction may not be greater than the value prescribed for the bearing wall system. For example, a concrete bearing wall system in the north-south direction (system A2a, SEAOC Table 1-G, R_w 6) and a steel special moment resisting frame (SMRF) in the east-west direction (system C1a, SEAOC Table 1-G, $R_w = 12$) will require $R_w = 6$ in both directions. Refer to SEAOC 1E3b. In SEAOC, this applies to Seismic Zones 3 and 4. For this manual it will apply to all zones.

(5) *Height limits.* In Seismic Zones 3 and 4, some approved structural systems are restricted by height limitations. For example, buildings over 160 feet in height must be special moment resisting frames or dual systems of steel or concrete with SMRF. Refer to SEAOC Table 1-G for applicable height limits. Note the exceptions of SEAOC 1D7.

4-6. C-factor and the building period, T.

a. General. For a given value of the site coefficient, 5, the factor C is dependent on the period of vibration, T, of the structure, as shown in SEAOC equation 1-2. Table 4-1 gives values of C as a function of T for four site profiles (S_1, S_2, S_3 and S_4). Figure 4-3 illustrates the relationship of C to T graphically. The plateau of the plot shown in figure 4-3 represents the maximum value of C, which is 2.75. The period of vibration is the time required for one complete cycle of oscillation of an elastic structure in a particular mode of vibration. The building period referred to in the seismic provisions of this manual is the fundamental period of vibration for each of the two translational directions of the building (the transverse and the longitudinal). The value of T may be determined by Method A or Method B. Method A may be used for all buildings, without qualification. There are limitations on the use of Method B.

PERIOD T Seconds	$C = 1.25S/T^{2/3}$			
	$S_1 = 1.00$	$S_2 = 1.20$	$S_3 = 1.50$	$S_4 = 2.00$
0.25	2.75	2:75	2.75	2.75
0.30	2.75	2.75	2.75	2.75
0.35	2.53	2.75	2.75	2.75
0.40	2.31	2.75	2.75	2.75
0.45	2.13	2.56	2.75	2.75
0.50	1.99	2.39	2.75	2.75
0.60	1.76	2.11	2.64	2.75
0.70	1.59	1.90	2.38	2.75
0.80	1.45	1.74	2.18	2.75
0.90	1.34	1.61	2.01	2.68
1.00	1.25	1.50	1.88	2.50
1.10	1.17	1.41	1.76	2.35
1.20	1.11	1.33	1.66	2.21
1.30	1.05	1.26	1.57	2.10
1.40	1.00	1.20	1.50	2.00
1.50	0.95	1.14	1.43	1.91
1.75	0.86	1.03	1.29	1.72
2.00	0.79	0.94	1.18	1.57
2.50	0.68	0.81	1.01	1.35
3.00	0.60	0.72	0.90	1.20
3.50	0.54	0.65	0.81	1.08
4.00	0.49	0.59	0.74	0.99

Table 4–1. C vs T for S_1, S_2, S_3, and S_4.

b. Method A. To calculate T by Method A, only the height of the building (h_n) and the value of C_t need be known for use of SEAOC equation 1-3. C_t is determined from the type of lateral force resisting system (e.g., steel moment frame, reinforced concrete moment frame, eccentric braced steel frame). An alternative for concrete or masonry shear wall systems may be used (SEAOC eq 1-4) if the shear wall dimensions are known.

c. Low-rise buildings. Short buildings have short periods of vibration. Without any calculation, it can be assumed that C equals 2.75 (the maximum value). Table 4-2 gives the value that T must exceed for C to be less than 2.75. If only Method A is used, table 4-3 may be used to estimate the height that the building must exceed to have C less than 2.75 for each of the values of C_t in SEAOC equation 1-3. For example, if a reinforced concrete special moment resisting frame building (C_t = 0.030) with an S-factor equal to 1.5 is 50 feet in height, by Method A, C equals 2.75 (table 4-3). However, if Method B is used and T is calculated to be greater than 0.56 second (table 4-2), C may be less than 2.75. But in no case can the value of C be less than 80 percent of 2.75 (that is, the minimum value of C is 2.2).

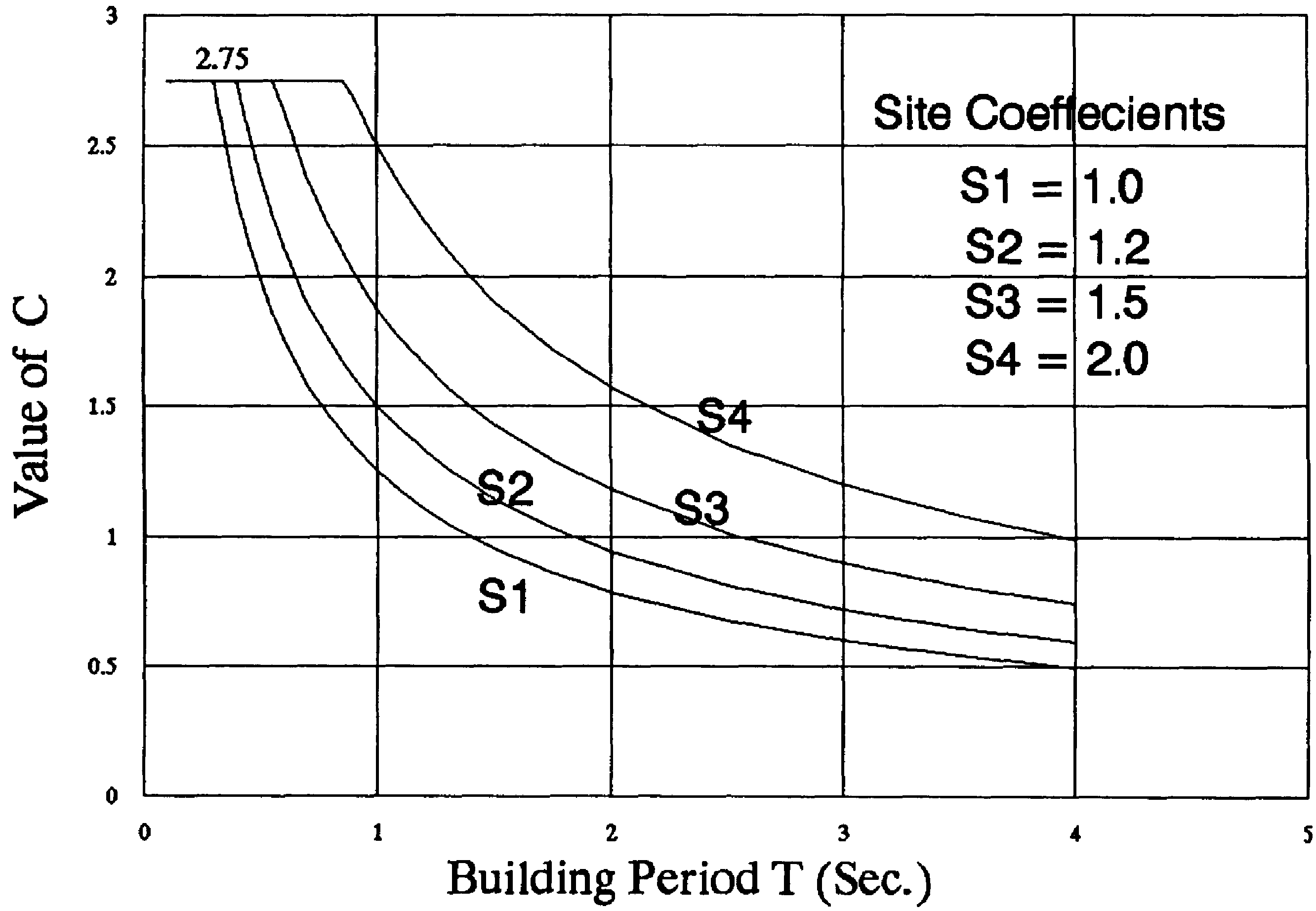


Figure 4-3. C vs T.

Soil Profile Site Coefficient, S	S_1 1.0	S_2 1.2	S_3 1.5	S_4 2.0
Period T* (sec)	0.31	0.40	0.56	0.87

*If the structure period is less than this value, C = 2.75. If it is greater, C <2.75. (See SEAOC Formula 1-2.)

Table 4-2. Value of T to be exceeded for C to be less than 2.75 when using Method A.

Site Coefficient, S		1.0	1.2	1.5	2.0
h_n** (ft)	C_t=0.035	18	26	40	72
	C_t=0.030	23	32	50	90
	C_t=0.020	38	54	85	150

**If height of building is less than this value, C = 2.75. If greater, C <2.75 (see SEAOC Formulas 1-2 and 1-3)

$$h_n = 0.207\ S^2/C_t^{4/3}$$

Table 4-3. Height to be exceeded for C to be less than 2.75 when using Method A.

d. Method B. When SEAOC equation 1-5 is employed (see fig 4-4), the most difficult challenge is the determination of the story displacements, delta$_i$. The story weights, w_i, are relatively simple to estimate, and almost any set of story forces, f_j, can be used (for example, the inverted triangular distribution obtained from SEAOC equation 1-8 usually gives good results), but the corresponding lateral story displacements must be calculated. The basic objective must be a realistic approach to calculating the actual period—rather than the manipulation of the structural model so as to obtain a "calculated" but nonvalid long period and low base shear. For simple structures, the lateral displacements required for SEAOC equation 1-5 can be obtained by hand calculation methods. For

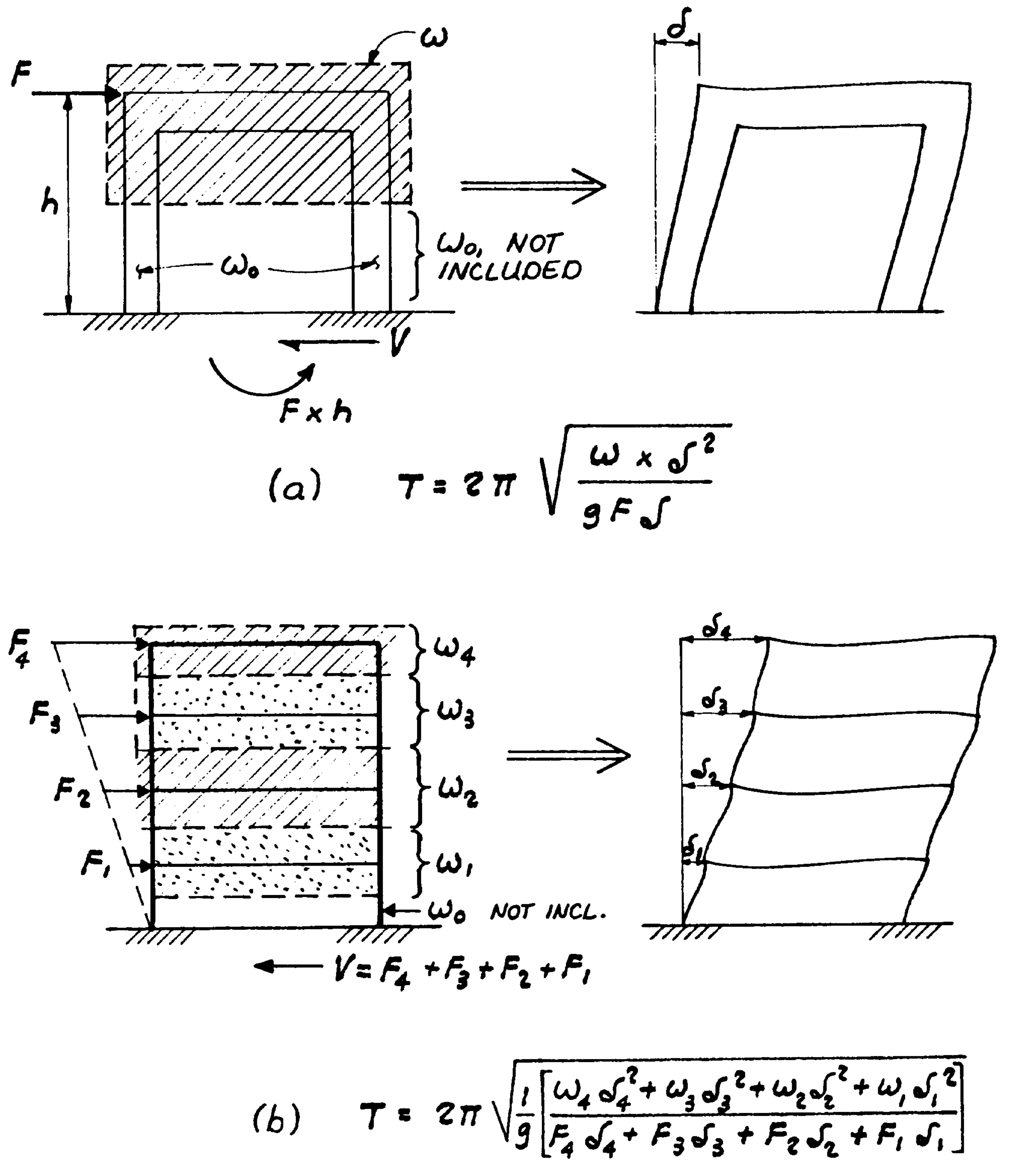


Figure 4-4. Period calculation by Method B.

complex structures, the calculations for lateral displacements become lengthy, so the aid of a computer program is normally used. Some programs that calculate member forces and frame deflections include a calculation of periods and mode shapes. Calculations must take into account all elements that stiffen the structure, even if they are not part of the seismic lateral force resisting system. Guidelines for developing a mathematical model of the structure to calculate structure periods can be found in TM 5-809-10-1/NAVFAC P-355.1/AFM 88-3, Chap 13, Sec A. It should be noted that assumptions that make the structure stiffer give a conservative result for calculating the design lateral force, but that the result is not conservative for drift calculations.

e. Lateral forces. Using an unrealistically long period for calculating the coefficient C can result in unconservative design forces. Because of the many parameters involved, it is difficult to establish a hard-and-fast rule for what the maximum value of the period T should be. In order to avoid a complex set of rules to limit the value of T for calculating C, a simple criterion was established. First, the period is calculated by using SEAOC equation 1-3; this is called Method A. In Method A, the period is designated TA, the resulting C-factor is designated C_A, and the design base shear is designated V_A. Next, the period may be calculated using structural properties and deformation characteristics (SEAOC eq 1-5). This is called Method B, and the resulting values are designated T_B, C_B, and V_B. The rule is that the design base shear V may not be less than 0.8 V_A. Because C is inversely proportional to $T^{2/3}$ (see SEAOC eq 1-2), if TA exceeds the values in table 42, the 0.8 V_A limit will be reached when T_B exceeds 1.4 T_a—that is, $(1.0/0.8)^{3/2}$.

(1) Maximum value of C. SEAOC equation 1-2 was developed by a curve-fitting process for determining the design base shear. It was proportioned in a manner to reach an upper plateau of C = 2.75 as shown in figure 4-3. Therefore, the maximum value of C is 2.75. It should be noted that SEAOC lE2a states that the “value of C need not exceed 2.75.” This is a form of code language that relates to this being a minimum standard; nothing in these recommendations prohibits the use of larger forces.

(2) Minimum value of C. As stated in SEAOC lE2a, the minimum value of the ratio C/R_w is 0.075. In other words, C may not be less than 0.075 R_w. For example, if a building is designed with R_w = 4, C will not be less than 0.30. If R_w = 12, C will not be less than 0.90. SEAOC lE2a states an exception for when code forces are scaled up by $3(R_w/8)$. This statement can be misleading. It means that the minimum value of C applies before the introduction of a $3(R_w/8)$ multiplier. The $3(R_w/8)$ multiplier does not apply to C. It is a multiplier applied after the base shear forces are calculated.

f. Lateral displacements. The maximum and minimum values prescribed above apply to lateral forces applied to the structure to determine the stresses in the structural elements and the required strengths. However, for some structures, member sizes are controlled by limits on lateral drift (SEAOC 1E8) rather than by stress limitations. This condition generally applies to structural steel moment resisting space frame systems with nonparticipating walls and partitions. SEAOC lE8c states that for satisfying the drift limitations, the 80 percent limitations and the 0.075 for C/R_w limits may be neglected. As an example, assume that a steel moment frame structure is designed by Method B, limited by 80 percent of Method A, and satisfies all the lateral force requirements except that the drift limits are exceeded. As an aid to illustrating this example, the following values are given for a building in an S_2 soil:

T_A = 0.65 sec, C_A = 2.0, and for
T_B = 1.30 sec. C_B = 1.26

(1) Eight percent of C_A equals 1.6. Therefore, C = 1.6 was used to determine the design forces.

(2) For C = 1.6, it is calculated that the drift limits are exceeded by 30 percent. This would mean that the structure would have to be stiffened by about 30 percent to satisfy the drift requirements.

(3) However, the applied forces were not consistent for this structure, which has a calculated period of 1.30 seconds. The applied forces were based on C = 1.6, which represents a structure with a period of 0.91 seconds (see table 4-1).

(4) If the forces were determined from C = 1.25 to be consistent with the period of 1.30 seconds, the calculated drifts would be reduced by about 20 percent. Thus, the structure would only have to be stiffened by 10 percent to satisfy the drift requirements.

(5) Note that the result of using this procedure has the net effect of reducing both the stresses and the drift, but does not require an undue increase in the sizes of the structural elements to satisfy the limits imposed by an empirical equation (SEAOC eq 1-3) based on approximations.

(6) This procedure is valid only if the period calculated by Method B is properly substantiated.

g. Calculation of F_t. The period T is also used to calculate F_t in SEAOC equation 1-7. The value of

T used for F_t will be consistent with the T used for the value of C.

(1) If the value of C is obtained by using T from Method A, then T from Method A will be used for calculating F_t.

(2) If the value of C is obtained by using T from Method B, without triggering the 80 percent limit in SEAOC 1E2b(2), then T from Method B will be used for calculating F_t.

(3) If the value of C is limited by 80 percent of the value obtained from Method A, then T will be determined by reversing SEAOC equation 1-2 to solve for the value of T:

$$T = (1.25\ S/C)^{3/2} \qquad \text{(eq 4-1)}$$

where C is 80 percent of the value obtained by using T from Method A. Note that the value of T will be greater than that obtained by Method A and less than that obtained by Method B.

4-7. Base shear. For most buildings, seismic design utilizes the static lateral force procedure, in which the dynamic response of the building is represented by an equivalent static lateral force. The base shear, the total lateral force on the building, is discussed in this paragraph; the distribution of this force over the height of the building is discussed below.

a. Design base shear equation. The design base shear, V, may be expressed by the equation

$$V = C_s \times W \qquad \text{(eq 4-2)}$$

where

C_s = the design base shear coefficient = V/W

W = the weight of the building

The design base shear coefficient of SEAOC equation 1-1 may be written

$$C_s = (ZC/R_W)\ I \qquad \text{(eq 4-3)}$$

where

ZC = the site spectrum

R_w = the response modification factor

I = the importance factor

b. Site spectrum. The site spectrum is ZC, where Z is the zone factor. C = 1.25 $S/T^{2/3}$, from SEAOC equation 1-2, where S = the site soil factor and T = the building period. Thus,

$$ZC = (1.25\ Z\ S/T^{2/3}) \qquad \text{(eq 4-4)}$$

Recognizing that a spectrum is a function of period, T, we call the quantity ZC, when plotted against period for a particular site with known values of Z and S, the site spectrum. A sample plot is shown in figure 4-5.

c. Building design spectrum. The site spectrum, ZC, would be used for design if the building were expected to remain elastic in the design event. Usually, however, we utilize the ductility and

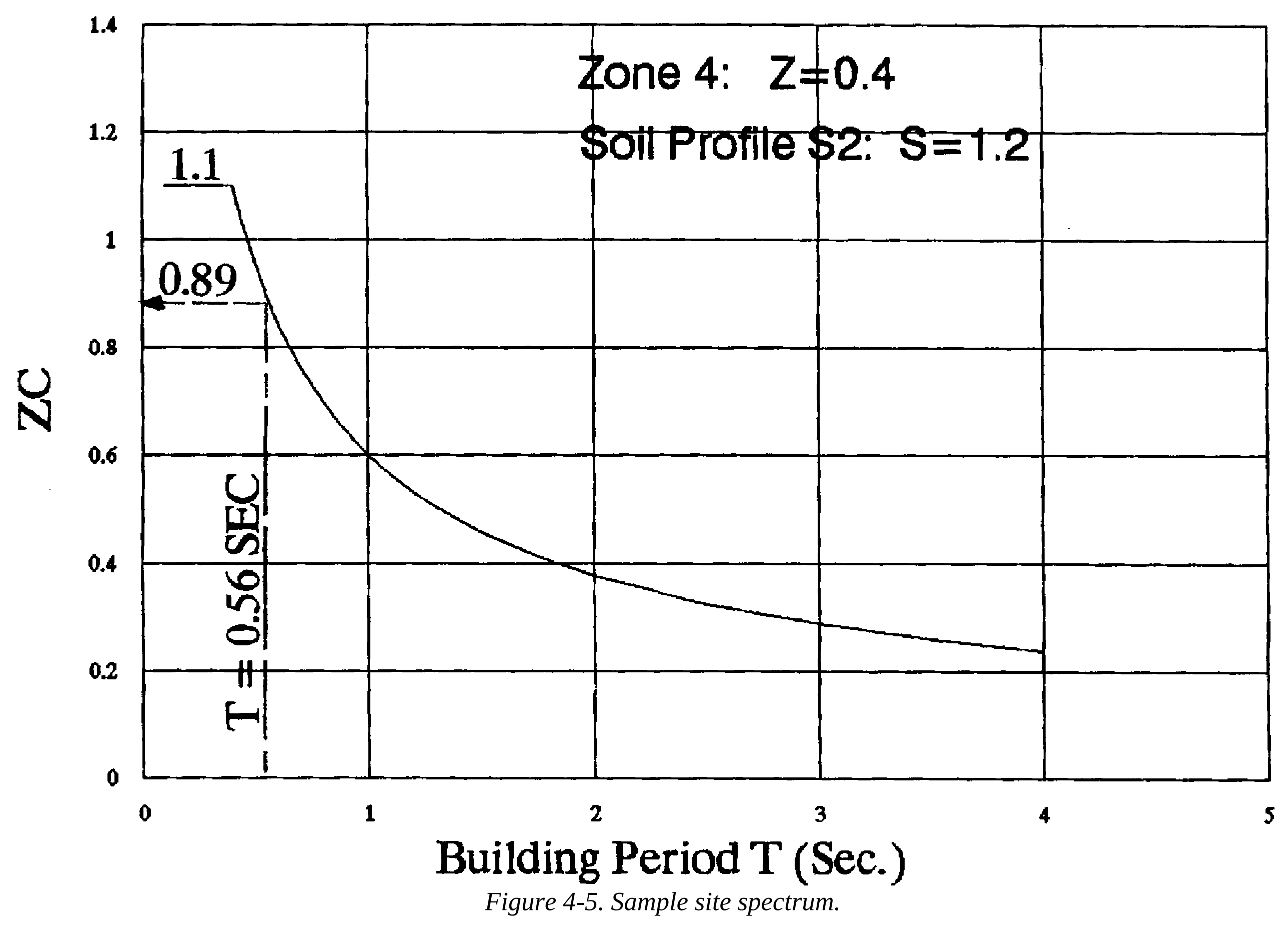


Figure 4-5. Sample site spectrum.

energy-absorbing characteristics of known structural systems to allow elastic design at a lower force level with the expectation of acceptable performance in the design event at a post-yield, nonlinear, inelastic level. This is accomplished by means of the response modification factor, R_w. The building base shear coefficient is ZC/R_w. The R_w-factor represents the ability of the structural system to dissipate energy without collapse while subjected to loads in excess of strength limits. The R_w values of SEAOC Table 1-G were selected by a consensus process based on past observations and judgment of the code-writing committee. They bring the base shear spectrum down to a level consistent with design forces used in past codes. When one of the basic structural systems is selected, the R_w-factor is determined and the building base shear coefficient (ZC/R_w) can be plotted against period. Figure 4-6 is a sample building design spectrum.

d. Design base shear. To develop a trial design for a particular structure, create a building design spectrum for the chosen system characterized by R_w. The period, T, of this structure is calculated, and for that value of T, the building design spectrum gives a base shear coefficient of ZC/R_w. For example, in figure 4-6, for T=0.56, ZC/R_w = 0.11. The design base shear is determined from SEAOC equation 1-1, which may be written $(ZC/R_w)IW$. The value of the factor I is determined from the occupancy categories of SEAOC Table 1-C. The values range from 1.0 to 1.25. Examples of various occupancy categories are given in chapter 3. When there is some doubt regarding the proper value of the I-factor, the decision will be made by the Agency Proponent. The factor W is the weight of the building as defined in SEAOC 1C and discussed in the following paragraph.

e. Weight. W, the total dead load and applicable portions of other loads, represents the total mass of the building. It includes the weight of the structural slabs, beams, columns, and walls, as well as nonstructural components such as partitions, ceilings, floor topping, roofing, fireproofing material, and fixed electrical and mechanical equipment. When partition loads are included in the design, their estimated weights will be used, but the value will not be less than 10 pounds per square foot of floor space. Miscellaneous items such as ducts, typical piping, and conduits can be covered by an additional 1 or 2 pounds per square foot. In storage areas, 25 percent of the design live load

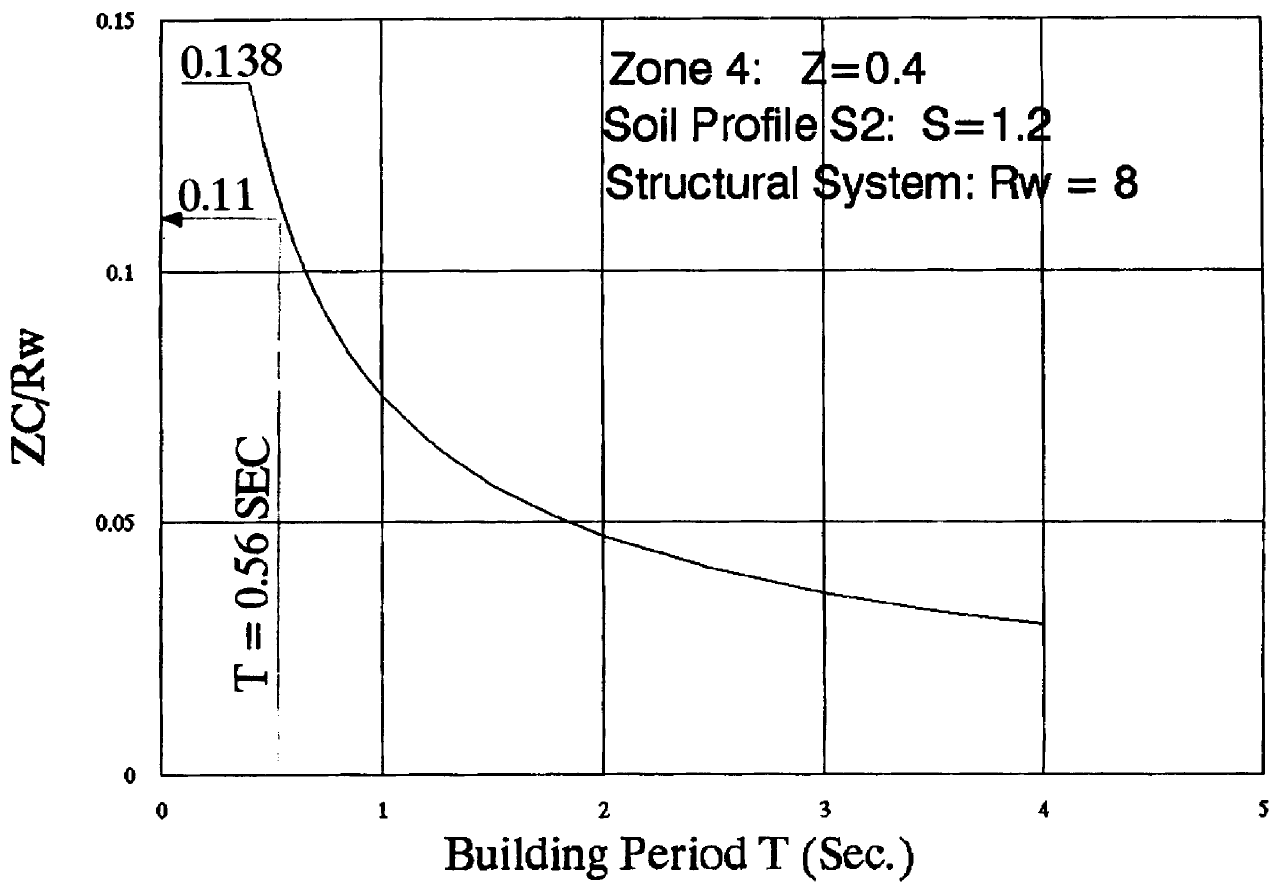


Figure 4-6. Sample building design spectrum.

shall be included in the seismic weight W. In areas of heavy snow loads, some or all of the design snow load must be included. At the initial stage of design, the estimated weights of the structural members will be used. After the final sizes of structural members are selected, the actual weights must be compared with the estimated weights. In addition to determining the overall weight W, the designer must determine tributary weights that are to be assigned to each floor, and also how these are to be distributed horizontally in the plan of the floor. Therefore, the calculations for W must be done in an orderly manner so that these tributary weights and their plan distributions can be accounted for.

(1) *Vertical distribution.* For vertical distribution, the weight W_x that contributes to story level x is calculated separately for each floor (refer to SEAOC 1E4). This generally includes the weight of the complete floor system, plus one-half the weight of the story walls and columns above the floor level and one-half of the weight of the story walls and columns below the floor level. If partitions are laterally supported top and bottom, their weight is divided between the two floor levels; however, if the partitions are freestanding, the total weight is included with the supporting floor level. Note that this discussion relates to the building as a whole: diaphragms are designed on a different basis.

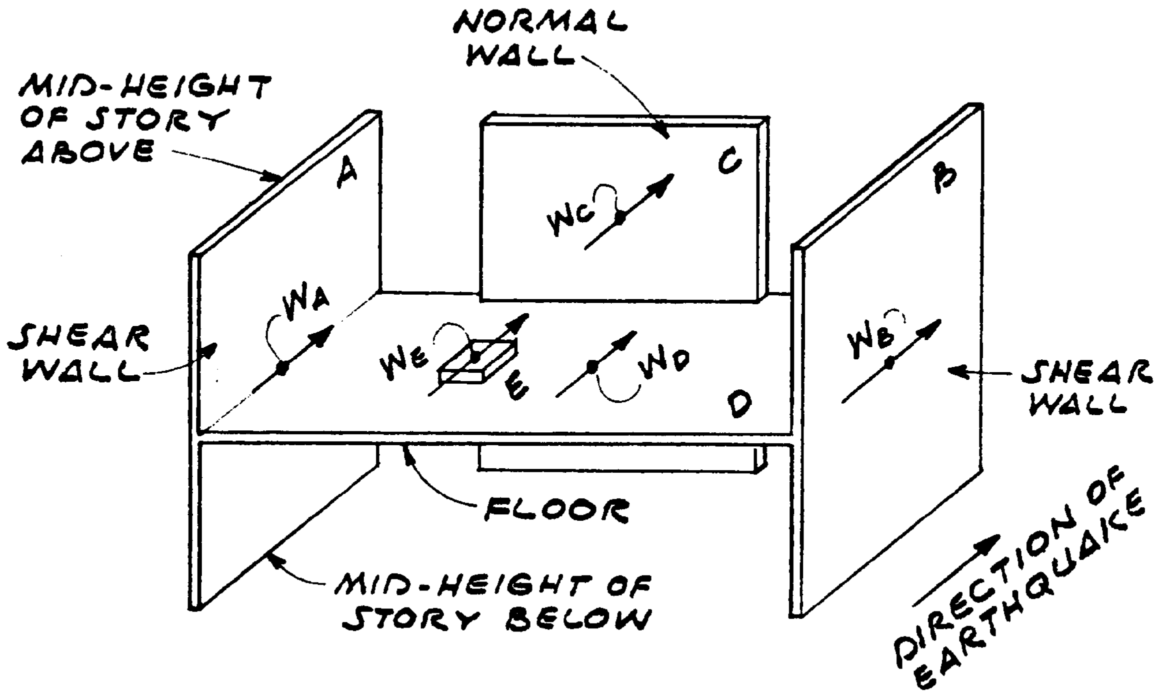
(2) *Horizontal distribution.* The horizontal distribution of weight at each floor level is required in order to calculate the center of mass (SEAOC 1E5) and the diaphragm forces (SEAOC 1H2j). The weight of the diaphragm and the elements tributary thereto (designated in SEAOC eq 1-11) include the floor system, tributary weights of walls and partitions, and other elements attached to the diaphragm. When designing diaphragms, it is assumed that lateral forces due to the weights of the shear walls stay in plane and need not be included in the analysis of the diaphragm that acts in the same direction. If, however, there is a vertical discontinuity in the vertical elements of the lateral force resisting system (e.g., if a wall does not extend to the base but stops at an upper level or has a reduction in stiffness), then the diaphragm is required to redistribute lateral forces. See SEAOC 1H2j(l)(b). The horizontal distribution generally consists of a combination of uniform and concentrated weights along the length of the floor plus concentrated weights tributary to the shear walls at the shear walls (see fig 4-7).

(3) Summation. The sum of the horizontal distribution of weights (in each direction of motion) will be equal to the story weight, and the sum of the story weights will equal the total weight W of the building, except that the bottom half of the first story generally distributes itself directly to the base and is not required to be included in the weight W (fig 4-3).

f. Snow loads. When the ground snow load is 30 psf or less, the effects of snow will not be combined with the seismic effects. When the ground snow load is greater than 30 psf, the effects of snow will be combined with the seismic effects. When snow and seismic effects are combined, 25 percent of the balanced snow load (i.e., 25% of the flat or sloped roof snow load) will be included. Unbalanced loads, drift loads, sliding snow, and rain-on-snow need not be included. For the seismic provisions, snow is considered an additional weight.

g. *Wind loads.* When wind governs, structures are ordinarily designed to remain elastic with stresses at an allowable level. Where seismic loads govern, structures are designed with ductile systems and increased loads on nonductile elements; the structures are expected to survive actual earthquake forces about three times as large as the design forces. This difference in approach reflects the relatively longer return period of the design earthquake compared with the design wind; accordingly, wind and seismic design are not comparable. The question of which loading governs arises in zones of low seismicity. As a rule, seismic loading should not be ignored unless the seismic base shear is less than one-third of the total wind force on the building.

h. The quantity $3(R_w/8)$. The building base shear coefficient (ZC/R_w) represents a force level for design, using ductile systems that are expected to have acceptable performance. As discussed in paragraph c above, the building base shear coefficient is obtained from the site spectrum ZC by means of the reduction factor R_w. During the earthquake, the building behaves in an inelastic manner such that the period lengthens, damping increases, other dynamic characteristics change, and the building will be subjected to forces less than those represented by ZC. The code implies that the forces will be reduced to about 3/8 ZC. Thus, the level of force and deflection that should be expected in the earthquake is approximately $3R_w/8$ times design or three times that used in the design of a basic frame building with an = 8. For components and connections that do not have the ductility of the system represented by R_w, there is a trade of strength for ductility: such components and connections are designed to have sufficient strength to withstand a higher force level. The SEAOC requirement is to modify the design



STORY WEIGHT FOR CALCULATION OF LATERAL FORCES:

W_x = WALLS + FLOOR + EQUIPMENT

$= W_A + W_B + W_C + W_D + W_E$

WEIGHT FOR DESIGN OF DIAPHRAGM

W_{px} = NORMAL WALLS + FLOOR + EQUIPMENT

$= W_C + W_D + W_E$

NOTE :

FLOOR WEIGHT W_D, INCLUDES FLOOR STRUCTURE, SUSPENDED CEILING, MECHANICAL EQUIPMENT (UNLESS TAKEN SEPARATELY AS W_E), AND (IF APPLICABLE) 20 PSF FOR PARTITIONS.

Figure 4-7. Tributary weights at a story.

by a factor that is three times $R_w/8$. There are several areas in which $3(R_w/8)$ should be considered.

(1) *Deflections.* The story drift limits of SEAOC 1E8 are design requirements for seismic systems, but the designer should be aware that in an earthquake drifts, of $3(R_w8)$ times the calculated drift can be expected. This is recognized in the requirements for deformation compatibility (SEAOC 1H2d) and building separations (SEAOC 1H21), and it should be recognized when detailing nonstructural items such as windows.

(2) *Design forces.* The $3(R_w/8)$-factor appears as a multiplier in the load combinations for discontinuous elements subject to overturning (SEAOC 1E7b), steel columns in frames (SEAOC 4D1), and in the design forces for exempted braced frames in low steel buildings (SEAOC 4G4).

(3) *Connections.* The $3(R_w/8)$-factor appears as a multiplier on the design forces for certain connections, for example, girder-column connections of steel ordinary moment frames (SEAOC 4E) and special moment frames (SEAOC 4F1b(2)), and the braces and related elements of light framed wall systems (SEAOC 4I3). The requirements for connections of bracing in braced frames (SEAOC

4G2(a) depend on whether or not the higher force level is used.

(4) *Other cases.* The $3(R_w/8)$-factor appears in other detailed requirements related to the basic categories in the foregoing paragraphs; for example, in eccentric braced frames, the limitation on the rotation of the link beam is tied to frame deflection at $3(R_w/8)$ times the drift due to the prescribed seismic forces (SEAOC 4H11b). In some cases, basic requirements are relaxed if the higher force level is provided for. Requirements concerning girder-column joint restraint are modified in SEAOC 4F7a(2)(d) and 4F7b(l)(a). The basic requirement of SEAOC 4G1c relating to the distribution of tension and compression braces in a line of bracing is modified by an exception to the requirement when the compression bracing acting alone has the strength for the higher force level.

4-8. Direction of forces. In general, the horizontal design earthquake forces are applied nonconcurrently in the direction of each of the main axes of the structure (SEAOC 1E1). In some cases a more severe condition may occur when the forces are applied in a horizontal direction not parallel to the main axes. The corner column of a building with a perimeter frame is an example of such an element. For some elements of a building the effects of concurrent motion about both principal axes should be investigated. These orthogonal effects are covered by SEAOC 1H1c. In the case of irregular buildings, the critical directions are determined by a process of iteration. The analysis is begun with any convenient pair of directions and is repeated until the critical directions are found.

a. Buildings. An independent design about each of the principal axes will generally provide adequate resistance for forces applied in any direction. Special consideration must be made at outside corners and re-entrant corners for the vulnerable effects of concurrent motions about both principal axes.

b. Structures other than buildings. For nonbuilding structures circular in plan, such as tanks, towers, and stacks, the design should be equally resistant in all directions. For four-legged structures substantially square in plan, 70 percent of the prescribed forces should be applied concurrently in the directions of the two principal axes, especially for purposes of designing for overturning effects on columns and foundations.

4-9. Distribution of forces. The total lateral force is distributed throughout the building in a manner that simulates the behavior of the building during an earthquake.

a. Path of forces. All of the inertia forces originating from the masses on and within the structure must be transmitted from their source to the base of the structure (see figs 4-8 and 4-9).

(1) Forces normal to the plane of a wall must be transferred either vertically to the floors above and below or horizontally to columns that are capable of transferring the forces vertically to the floors above and below. Normal walls are treated as elements of structures. The design forces will be governed by SEAOC equation 1-10.

(2) Diaphragms acting as horizontal beams must transfer inertia forces to the frames and/or shear walls. The design forces will be governed by SEAOC equation 1-11. The distribution of these forces is discussed in paragraph *d.*

(3) Frames and shear walls must transfer forces contributed from the diaphragms as well as their own inertia forces to the foundations. The design forces will be governed by SEAOC equations 1-1, 1-6, and 1-8.

(4) Forces applied to the foundations by the shear walls and frames must be transmitted into the ground. See chapter 10 for design of foundations.

(5) Connections between all elements must be capable of transferring the applied forces from one element to another. Special design requirements for connections are reviewed in paragraph 4-13.

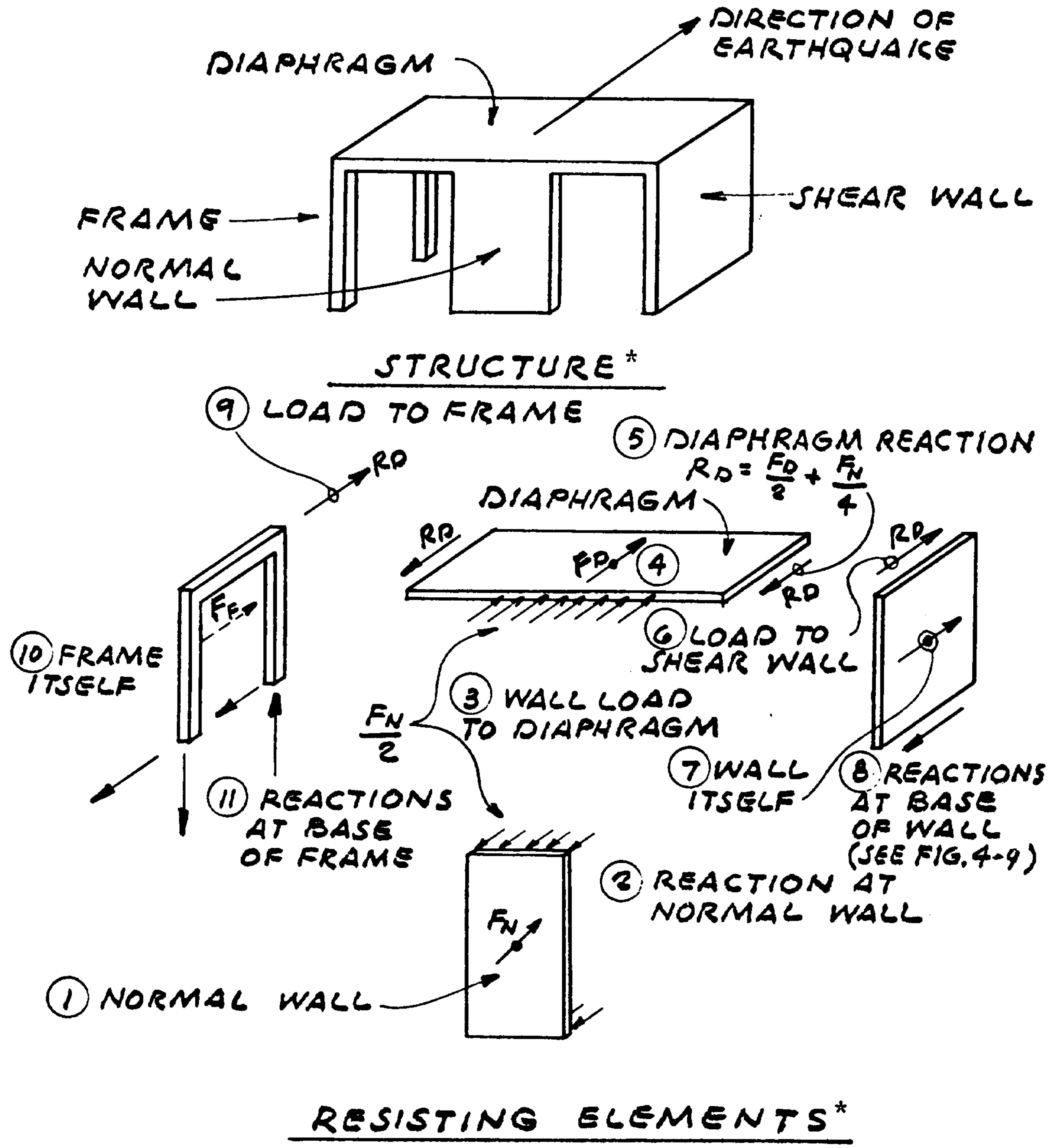
b. Vertical distribution of base shear. The total lateral force on the building is resisted by a shear and a moment at the base. Instead of calculating the forces and finding the base shear as the sum of these forces, the base shear is calculated (by SEAOC eq 1-1) and this force is distributed over the height of the building (by SEAOC eq 1-6). The application of seismic forces to a building is shown in figure 4-10. A sample format for determining story forces is shown in table 4-4. The procedure given is based on the assumption of a uniform building and is aimed at a reasonable evaluation of the relative maximum story shear (e.g., column (9) in table 4-4) envelope that will occur.

(1) *Regular buildings with T equal to or less than 0.7 second.* When the period of the building is equal to or less than 0.7 second, F_t will be equal to zero. Then SEAOC equation 1-8, the vertical distribution equation, will reduce to the following:

$$F_x = \frac{w_x h_x}{\sum_{i=1}^{n} w_i h_i} V \qquad \text{(eq 4-5)}$$

The story force F_x is distributed horizontally at level x in proportion to the weight distribution at that level (refer to fig 4-10).

(2) *Regular building with T greater than 0.7 second.* When the period of the building is greater



Note:* **Example shows flexible diaphragm. For rigid diaphragm, relative rigidities and torsion will be considered.

Figure 4-8. Path of forces.

than 0.7 second, a lateral force, F_t, is applied to the top level of the structure, usually the roof. F_t equals 0.7T times the lateral force V, as determined by SEAOC equation 1-7. F_t will vary from 5 percent (T = 0.7 second) to 25 percent (T = 3.6 seconds) of the lateral force V. The value of T is discussed in paragraph 4-6*g*. The remaining portion of the force (V - F_t) is distributed throughout the height of the structure in accordance with SEAOC equation 1-8. The total applied force at the top level of the structure will be $F_t + F_n$, where F_n is the value of F obtained from SEAOC equation 1-8 for the top level n (see fig 4-10).

(3) *Additional comments on F_t.* The rationale for F_t is based on the following assumption: For buildings with periods greater than 0.7 second (e.g., tall and/or flexible structures), the combined mode shape may depart from the straight-line

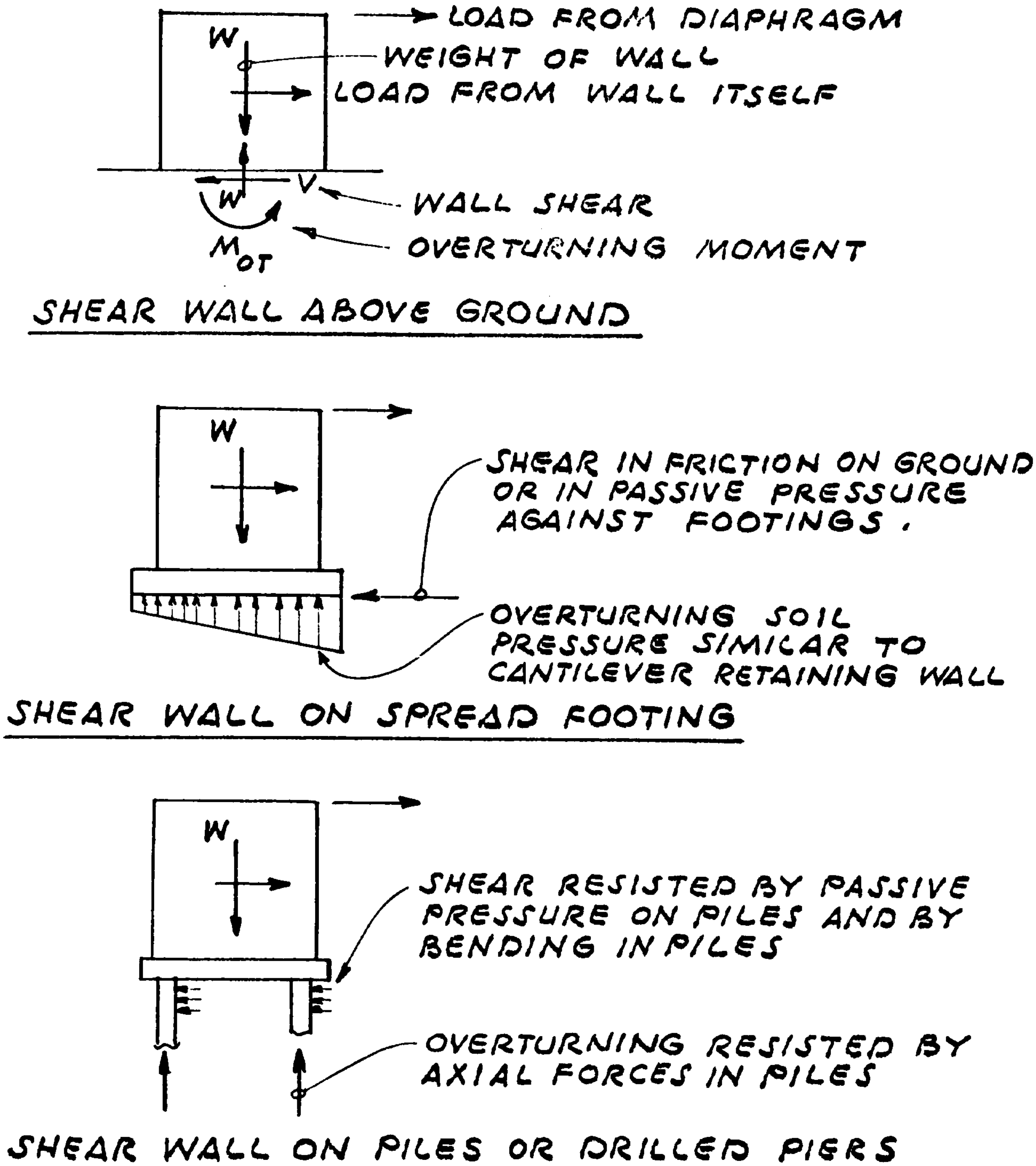


Figure 4-9. Transfer of forces to ground.

assumption (eq 4-3), and the effects of higher modes of vibration may become more significant. To account for this, a greater portion of the lateral force is assigned to the top of the structure by use of F_t from SEAOC equation 1-7. This additional force is intended to increase the shear force and the equivalent story acceleration at the upper stories; however, in some cases the strict application of F_t may result in excessive forces for roof diaphragms and excessive overturning moments at foundations. To lessen these effects for diaphragms, SEAOC 1H2j places a limit of $0.75ZIw_{px}$ on the required diaphragm force. A better approximation of the force distribution may be made by

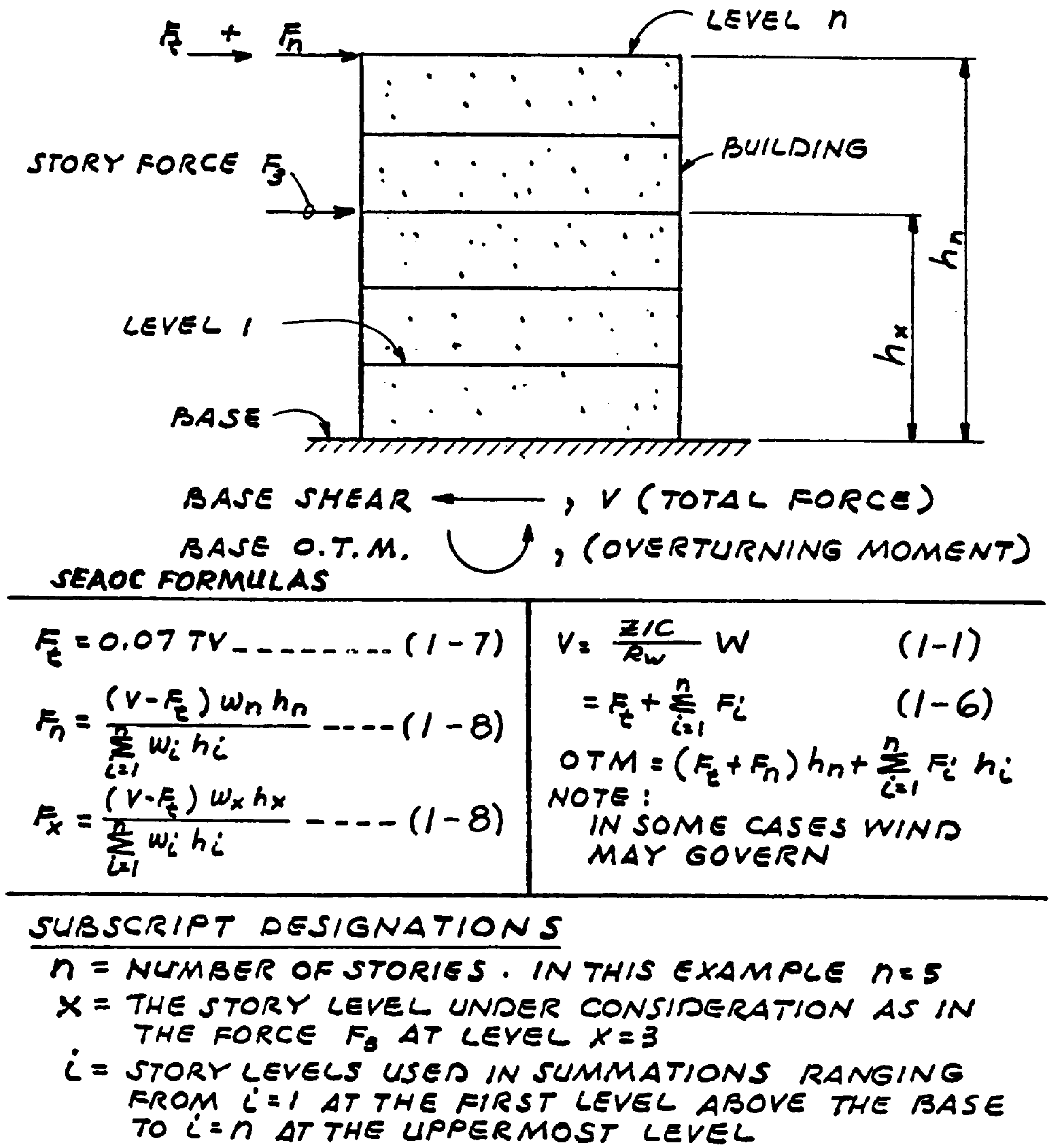


Figure 4-10. Seismic forces.

using the principles of dynamics, which include the significant modes of vibration (see below).

(4) *Irregular structures.* For structures with irregular configuration or framing systems, the lateral force distribution procedures for uniform buildings that are described above and prescribed by SEAOC equations 1-7 and 1-8 are not applicable; lateral force must be distributed by a rational procedure that takes into account the stiffness properties of the lateral force resisting system, the mass distribution, and the principles of dynamics.

c. Overturning. The overturning effects are determined by applying the story forces obtained from SEAOC equations 1-7 and 1-8, as illustrated in table 4-4 and figure 4-10. The structure must resist these forces in accordance with SEAOC 1E7. Other loading provisions related to overturning moment effects are SEAOC 1H1b, 1J4, 3B1, and 4D1b. In moment resistant frame structures, the overturning is resisted by a combination of coupled

Building: 7-story building Direction: Longitudinal (N-S)
$Z = 0.4$; $I = 1.0$; $R_W = 12$; $S = 1.5$; $h = 65.7$; $W = 10{,}540$
$C_t = 0.030$; $T_A = 0.69$; $C_A = 2.41$; $0.8C_A = 1.93$; $T_B = 0.76$; $C_B = 2.26$
$C = 2.26$; $T = 0.76$; $V = (ZIC/R_W)W = 0.075\ W = 791.$
$F_t = 0.07\ TV = 0.054\ V$; $F_X = (V-F_t)wh/\Sigma wh = 0.946\ V(wh/\Sigma wh)$

Level (1)	h ft. (2)	Δh ft. (3)	w kips (4)	Σw (5)	(2)x(4) wh (6)	$\frac{wh}{\Sigma wh}$ (7)	F kips (8)	Σ(8) V kips (9)	(3)x(9) ΔOTM kip-ft (10)	Σ(10) OTM kip-ft (11)	(9)÷(5) $\frac{F_t+\Sigma F_i}{\Sigma w_i}$ (12)*
							F_t=43				
Roof	65.7		1,410		92,637	0.228	171				
		8.7		1,410				214	1,862		0.152
7	57.0		1,460		83,220	0.205	153			1,862	
		8.7		2,870				367	3,193		0.128
6	48.3		1,460		70,518	0.174	130			5,055	
		8.7		4,330				497	4,324		0.115
5	39.6		1,460		57,816	0.142	106			9,379	
		8.7		5,790				603	5,246		0.104
4	30.9		1,460		45,114	0.111	83			14,625	
		8.7		7,250				686	5,968		0.095
3	22.2		1,460		32,412	0.080	60			20,593	
		8.7		8,710				746	6,490		0.086
2	13.5		1,830		24,705	0.061	46			27,083	
		13.5		10,540				792	10,692		0.075
GRD.	0									37,775**	
Σ			10,540		406,422	1.001	792		37,775		

*For use in SEAOC Eq 1-11.
**For foundation overturning moments, this value may be reduced by 2825 kip-ft (43x65.7) when F_t is neglected. See SEAOC 1J4.

Table 4-4. Force distribution.

axial column forces and bending moments in the column. In shear wall buildings, the overturning moments are resisted by flexure in the shear walls. The application of the statis design forces can create an apparent overturning instability condition that is difficult to reconcile with observations in earthquakes where actual loadings are cyclic and dynamic. SEAOC 1J allows the force F_t to be omitted for determining overturning at the foundation-soil interface.

d. Horizontal distribution of story shear.

(1) *Horizontal forces.* At each level the diaphragm distributes lateral forces from above to shear walls and frames below. The nature of the

distribution depends on the relative rigidities of the diaphragm and the resisting elements below. To account for uncertainties in the locations and distribution of weights that contribute to the earthquake forces, the calculated center of mass will be assumed to be shifted by five percent of the building dimension in either direction (SEAOC 1E5b). For rigid diaphragms, an additional eccentricity may be required.

(2) *Horizontal torsional moments.* For rigid diaphragms (i.e., not flexible per SEAOC 1E6a), where the center of rigidity of the vertical elements of the lateral force resisting system (frames or shear walls) is not coincident with the center of mass, provisions must be made for this eccentricity plus an additional “accidental” eccentricity of 5 to 15 percent of the building dimension which is intended to account for uncertainties. For a symmetrical building, a minimum eccentricity of 5 percent of the building dimension perpendicular to the direction of force is required. When torsional irregularities exist, an amplification factor determined by SEAOC equation 1-9 is applied to the 5 percent eccentricity (see chapter 5).

(3) *Distribution between shear walls and frames (dual systems).* When a dual bracing system is used (SEAOC Table 1-G, Category D), a rigidity analysis must be made to determine the interaction between the walls and the frames.

e. Orthogonal effects. SEAOC 1H1c refers to the effects on a structure due to forces induced in directions not parallel to the direction of resistance under consideration. It does not refer to torsion in general; that is covered by SEAOC 1E6. Orthogonal effects are involved in the following case—

(1) The vertical elements of the lateral force resisting system are not parallel to or not symmetric about the major orthogonal axes of the lateral force resisting system (plan irregularity Type E of SEAOC Table 1-F).

(2) The structure has torsional irregularities (Type A of SEAOC Table 1-F) for both major axes.

(3) An element is common to two intersecting systems. The most common example is the corner column of a perimeter frame; the maximum overturning force on the column occurs when the direction of force is oblique to the main axes of the frame.

f. Participating elements. Elements that are not designated as lateral force resisting elements may nevertheless participate in resisting lateral forces. All gravity load carrying elements not designed to be part of the lateral force resisting system must be analyzed to determine if they are compatible with the lateral force resisting system (see SEAOC 1H2d). Any element that is not strong enough to resist the forces that it attracts or the interstory drifts that occur will be damaged unless it is isolated from the lateral force resisting system.

4-10. Vertical seismic forces. Vertical components of ground motion are not usually calculated. Stresses are considered to fall within the usual one-third increase that is allowed for earthquake effects. In cases where gravity load is depended on for stability, and where seismic load tends to reduce the total load, there are special provisions for using reduced dead loads. Such provisions include the 0.85 factor for dead load in SEAOC 1H1b. These reduced loads apply to axial compression due to gravity in concrete columns and walls when subjected to seismic overturning moments and uplift forces and to beam bending moments due to gravity when combined with seismic bending moments in the opposite direction (i.e., bending moment reversal).

a. Horizontal elements. In Zones 3 and 4, special considerations must be given to the effects of vertical accelerations on horizontal prestressed elements (especially those with draped prestressing) and horizontal cantilevers (SEAOC 1E10). For investigating the effects of vertical accelerations on horizontal prestressed elements an approved procedure is to rely on only 50 percent of the dead load as a minimum gravity load when applying the lateral forces. Horizontal cantilever elements should be checked for the capacity of the elements to resist a net upward force of 20 percent of the dead load.

b. Hold-downs. In Seismic Zones 3 and 4, the design of hold-downs to resist overturning moments and uplift forces will use a maximum of 0.85 of the dead load for gravity resistance. The load provisions related to hold-down resistance are in SEAOC, 1E7, 1H1b, 3B1, and 4D1b.

4-11. Detailed design requirements. SEAOC 1H is intended to cover a variety of concerns other than the determination of lateral forces on the building as a whole (SEAOC 1E) and the parts of the building (SEAOC 1G). These topics are discussed at appropriate places in the manual. Some requirements and details for satisfactory performance under earthquake conditions are enumerated and discussed in the following paragraphs. Also, refer to the discussion of damage control features in chapter 2.

a. Separation of structures (SEAOC 1H21). In past earthquakes the mutual hammering received by buildings in close proximity to one another has caused significant damage. The simplest way to prevent damage is to provide sufficient clearance so that free motion of the two structures will result. The motion to be provided for is produced partly by the deflections of the structures themselves and partly by the rocking or settling of foundations. The gap must equal the sum of the total deflections from the base of the two buildings to the top of the lower building.

(1) In the case of a normal building less than 80 feet in height using concrete or masonry shear walls, the gap shall be not less than the arbitrary rule of 1 inch for the first 20 feet of height above the ground plus ½ inch for each 10 feet of additional height.

(2) For higher or more flexible buildings, the gap or seismic joint between the structures should be based on $3(R_w/8)$ times the sum of the deflections determined from the required (prescribed) lateral forces. If the design of the foundation is such that rotation is expected to occur at the base due to rocking or due to settlement of foundations, this additional deflection (as determined by rational methods) will be included.

b. Seismic joints. Junctures between distinct parts of buildings, such as the intersection of a wing of a building with the main portion, are often designed with flexible joints that allow relative movement. When this is done, each part of the building must be considered as a separate structure that has its own independent bracing system. The criteria for separation of buildings in paragraph a above will apply to seismic joints for parts of buildings. Seismic joint coverages will be made flexible, waterproof, and architecturally acceptable.

c. Elements that connect buildings. Certain types of structures commonly found in industrial installations are tied together at or near their tops by connecting parts such as piping, conveyors, and ducts. The support of these elements will allow for the relative movement between buildings.

d. Bridges between buildings. Clusters of buildings are often connected by bridges. In most cases it would not be economically feasible to make bridges sufficiently rigid to force both buildings to vibrate together. A sliding joint at one or both ends of the bridge can usually be installed.

e. Stairways. Concrete stairways often suffer seismic damage because they act like struts between the connected floors. This damage can be avoided by anchoring the stair structure at the upper end and providing a slip joint at the lower end of each stairway, or by tying stairways to stairway shear walls.

f. "Short column" effects. Whenever the lateral deflection of any column is restrained, when full-height deflections were assumed in the analysis, it will carry a larger portion of the lateral forces than assumed. In past earthquakes, column failures have frequently been inadvertently caused by the stiffening (shortening) effect of deep spandrels, stairways, partial-height filler walls, or intermediate bracing members. Unless considered in the analysis, such stiffening effects will be eliminated by proper detailing for adequate isolation at the junction of the column and the resisting elements.

4-12. Deformation requirements. Deformations will be governed by the provisions for story drift limitations (SEAOC 1E8), building separations (SEAOC 1H21, and para 4-11*a*), deformation compatibility (SEAOC 1H2d), diaphragm deformation (SEAOC 1H2j and chap 6, and exterior elements (SEAOC 1Hd(2)).

a. Elements to be included. For determining compliance with the deformation provisions, only structural elements should be considered in the stiffness calculations. It is unconservative to include the stiffness participation of nonstructural elements without substantiated data. This is in contrast with the assumptions used in the period calculation for obtaining values for C. Thus, it is not uncommon to have one set of stiffness assumptions for calculating the total design lateral forces and another set of stiffness assumptions for calculating the design lateral displacements. It is acceptable to calculate the lateral deformations based on lateral forces corresponding to a building period calculated by Method B, even if the resulting forces are smaller than 80 percent of the lateral forces of Method A specified in SEAOC 1E2. An example is given in paragraph 4-6*f*.

b. P-delta effects. The secondary effects of lateral deformation (P-delta effects), when significant, must be investigated to ensure lateral stability. Criteria for inclusion of P-delta effects are prescribed in SEAOC 1E9.

4-13. Connections between elements. The various elements of the lateral force resisting system will be connected to each other by positive means so as to make the load path complete, and the connections will be adequate and consistent with the basic assumptions and distribution of forces.

a. Continuity.

(1) *Portions of structures.* When a building consists of two or more portions, such as larger/smaller or center/wings, the portions will be tied as prescribed in SEAOC 1H2e(1).

(2) *Horizontal capacity.* At supports for beams, girders, and trusses, a horizontal capacity will be provided as prescribed in SEAOC lH2e(2).

(3) *Collectors.* Collector elements will be provided where needed to transfer forces from a point of origin at one place in the building to a point of

resistance in another place, as prescribed in SEAOC 1H2f.

b. Forces to be considered. Joints and connections will be designed for forces consistent with all possible combinations of loadings. In addition to the prescribed forces and load combinations, the designer will consider additional load effects due to settlement, shrinkage, creep, and thermal expansion, temporary erection loads, and differential settlements. Rotational effects or torsions resulting from eccentric connections must be considered. In general, elements and members should be detailed so that torsion and secondary moments are held to a minimum at the connections.

c. The strength of connections.

(1) Connections between diaphragms and vertical elements of the lateral force resisting system. Diaphragm shears, based on SEAOC equation 1-11, will be transferred to shear walls and frames by means of appropriate connectors, such as bolts, embedded bolts, and welded studs.

(2) Connections within systems. Members of the horizontal and vertical systems (diaphragms, shear walls, and frames) will be connected as provided at appropriate places in this manual.

(3) Special loads. In some cases, design forces for connections are increased by a multiplier. The forces obtained from analysis based on SEAOC equation 1-1, 1-10, or 1-11, are multiplied by a particular number or by the quantity $3(R_w/8)$. The purpose of these multipliers is to ensure that the capacity of the building is governed by its elements, not by its connections. In these cases, the intention is to provide greater strength in the connection to offset its lack of ductility compared with the resisting system, which has an assigned R_w value.

d. Special elements. Special design requirements are included in SEAOC 1H for exterior panels (SEAOC 1H2d(2)), anchorage of concrete or masonry walls (SEAOC 1H2h), and wood diaphragms used for lateral support of concrete or masonry walls (SEAOC 1H2j(3)).

e. Details. Details of connections will admit to a rational analysis in accordance with well-established principles of mechanics.

4-14. Diaphragms. Diaphragms will be designed to resist forces prescribed by SEAOC 1H2j. Not only does a diaphragm transfer forces, but it must resist the inertia forces of its own weight, The design forces, given by SEAOC equation 1-11, are different from building story forces because diaphragms tend to respond as sub-elements within the building structure. Diaphragms are discussed in detail in chapter 5.

4-15. Elements and components. Parts of buildings other than the major horizontal and vertical elements of the lateral force resisting system will be designed to resist forces prescribed by SEAOC 1G and to transfer these forces to the structural system of the building through proper connections. SEAOC 1G is concerned with elements when they are loaded by inertia forces due to their own weight rather than by forces they carry as part of a lateral force resisting system. Three sets of things are considered in SEAOC 1G: elements of structures (referred to below as structural elements), permanent nonstructural components and their attachments (referred to below as architectural components), and the attachments for permanent equipment supported by structures (referred to below as mechanical and electrical components).

a. Structural elements. These elements, also called “parts and portions of structures,” use the horizontal force factors (C_p value) of Part I of SEAOC Table 1-H. Structural elements include walls and parapets with lateral loads normal to the flat surface. These out-of-plane effects are discussed in chapter 6.

b. Architectural components. These components use the C_p value of Part II of SEAOC Table 1-H. These components include partitions, ornamentation, suspended ceilings, exterior panels, and storage racks. They are covered in chapter 11.

c. Mechanical and electrical components. These components, which use the C_p value of Part III of SEAOC Table 1-H, are covered by chapter 12 and include chimneys and smokestacks, as well as equipment and machinery.

4-16. Nonbuilding structures. This manual is primarily concerned with the design of buildings; however, provisions are also included for some structures other than buildings. When these structures are designed in accordance with SEAOC equation 1-1 in SEAOC 1E2, an R_w value of 3 to 5 is used, as specified in SEAOC Table 1-I. These lower values are justified by the assumption that these structures will generally have lower damping characteristics, less inelastic deformation capacity, and less redundancy than typical buildings. Procedures and guidelines for nonbuilding structures are included in chapter 13.

4-17. Planning. Planning involves predesign studies and preliminary design. Design development and final design are discussed in paragraph 4-18.

a. Predesign studies.

(1) *Site planning.* Site planning considers geologic, foundation, and tsunami (sea-wave) hazards as well as seismicity. Structures will not be sited

over active geologic faults, in areas of instability subject to landslides, where soil liquefaction is likely to occur, or in areas subject to tsunami damage.

(a) Seismic zones. The probability of the severity, frequency, and potential damage from ground shaking varies in different geographic regions. Regions with similar hazard factors are identified as seismic zones.

(b) Fault zones. Damage that is directly or indirectly caused by ground distortions or ruptures along a fault cannot be eliminated by design and construction practices; therefore site planning must avoid these particularly hazardous locations.

(c) Tsunami protection. Each region along the Pacific coast must be separately and carefully investigated for its tsunami-generating characteristics. Particular coastlines, inlets, and bays of the Pacific Ocean boundary are resonators of tsunami waves and may greatly amplify the effects. Assuming that tsunami warning services can ensure the safety of human life, there is as yet no hard-and-fast rule for establishing safety and economic standards. Where feasible, power plants, oil storage tanks, and other strategic facilities should be located on high ground, out of reach of high water.

(d) Other hazards. Other hazards associated with earthquakes include subsidence and settlement due to consolidation or compaction, landslides, and liquefaction. Liquefaction is a common occurrence in relatively loose, cohesionless sands and silts with a high water table. The earthquake motions can transform the soil into a liquefied state as a consequence of the increase in pore pressure. This can result in a loss of strength in bearing capacity of the soil supporting a building, causing considerable settling and tilting. Also, this loss of strength can occur in a subsurface layer, causing lateral movement of surficial soil masses of several feet, along with ground cracks and differential vertical displacements. These movements have severed pipelines and damaged bridges and buildings. There are several ways to stabilize the ground, such as providing drainage wells, pressure grouting, or removing the liquefiable zone, but often the susceptible area is too extensive for an economical solution. The exposure to these hazards varies with the geography, geology, and soil conditions of the site and the type of structure to be constructed. The professional judgment of geologists, geotechnical engineers, and structural engineers will be used to establish reasonable standards of safety.

(2) *Conceptual planning.* Collaboration of the architect and structural, mechanical, and electrical engineers is necessary to establish a concept for the overall building system, to establish design criteria for the specific facility, to select the materials of construction, and to reconcile the conflicting requirements of architectural, structural, mechanical, and electrical systems. A quick estimate of the design lateral earthquake forces should be made to establish approximate component sizes and the layout of the lateral force resisting system. The locations of seismic joints and the possibility of future expansion must be considered at this stage.

b. Preliminary design.

(1) *Selection of system.* Before selecting the structural system, it is essential that the planners be familiar with the fundamentals of seismic design. Consideration should be given to the architectural and functional requirements, the need for future modifications related to use, the need for damage or drift control, and an evaluation of the economics and availability of the specific materials and the construction practices at the site.

(2) *Redundancy.* It is strongly recommended that the lateral force resisting system be made as redundant as possible; multiple lines of resistance are preferable to perimeter resistance only, and multiple bents or bays of resistance in each bracing line are much more desirable than a single bent or bay. Good torsional rigidity is also essential. The object is, first, to create a system that will have its inelastic behavior distributed nearly uniformly throughout the plan and elevation of the system and, second, to have such a degree of redundancy that softening or failure of a particular element can result in load redistribution to the associated redundant elements without the possibility of collapse.

(3) *Damage control considerations.* Damage to the structure and repairability of the structure were not prime considerations in the development of the R_w-factors. Thus, it may be appropriate for the engineer to consider these concerns and increase the level of loading, stiffness, and detailing requirements if it is desired to control the amount of damage and/or decrease the cost of repairing the damage resulting from the earthquake.

(4) *Selection of trial structural member size.* Some of the structural members of a building are governed by the gravity load design, and their size selection may not be affected by the addition of the seismic loads. For these members the sizes will have been determined by the usual requirements for dead and live loads. For the sizes of members that form the seismic lateral force resisting system, a trial-and-error process is generally required because of the relationship between design lateral forces, structure periods, and lateral drift limitations. For the first trial design, lateral forces are obtained from approximations of period and weight. SEAOC equation 1-3 may be used for periods. The base

shear and story forces are determined. Next, trial member sizes are selected by using approximate calculations and judgment. Finally, a preliminary analysis is made, and the trial sizes are confirmed or revised. If there are substantial revisions to the initial trial sizes, the structure period and the lateral drift will change, and a reanalysis may be required.

4-18. Design.

a. Design development. This phase of the design process involves identification and location of primary structural elements, determination and distribution of lateral seismic forces, preparation of design calculations, detailing of connections, detailing of nonstructural parts for damage control, and preparation of clear, complete contract drawings and specifications.

b. Final design considerations. After the structural elements have been selected and analyzed, a final design check must be made to verify that the initial assumptions are correct, and whether or not the resulting structure satisfies the intent of the seismic provisions.

(1) Comparison of final sizes with initial estimates.

(a) *Weights.* It is necessary to compare the final weights of the building with the weight used to determine the seismic forces. If the weight has increased significantly (say, over 5 percent), redesign will be necessary.

(b) *Stiffness.* If the final member sizes are substantially different from the initial estimates, a re-evaluation of the design will be necessary. If the relative stiffnesses of the varying elements have changed significantly, the distribution of lateral forces must be re-evaluated.

(c) *Period.* If the initial period was determined by Method B using structural properties and deformation characteristics, such as in SEAOC equation 1-5, the initial stiffness and weight properties must be compared with the final properties of the structure. If the final period is shorter than the initial period that was used to calculate the lateral forces, a new set of forces must be calculated and applied to the structure.

(d) Displacements. If the final stiffness, period, or forces have changed substantially, displacements will have to be recalculated to check for compliance with the various provisions for drift and deformation.

(2) *Path of forces.* Upon completion of the design, a final check will be made to determine that all the inertia forces can be transmitted without instability from their source to the base of the structure.

(3) *Details.* It is necessary to check the structural details to ensure that the intent of the design calculations and the seismic design detailing is properly provided for on the construction drawings.

(4) *Specifications.* The specifications must be checked to ensure that the intent of the design calculations, material strength assumptions, and seismic design detailing is properly provided for in the job specifications.